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Assessment on the Quality of Recycled Paper Mill Sludge Mixed with Oil Palm Empty Fruit Bunch Compost

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ABSTRACT

Recycled Paper Mill Sludge (RPMS) is currently disposed off in the landfill and the costs are becoming expensive. Therefore, an alternative disposal through land application of RPMS and empty fruit bunches (EFB) (as a bulking agent) compost requires investigation. This study was conducted to determine the physico-chemical characteristics of composted RPMS and EFB mixtures, their phytotoxicity and the effect of the composts on plant growth performance. Composting experiment was arranged in a completely randomized design (CRD) with four replicates. The RPMS were mixed with EFB in 3 ratios, that is 1:1, 1:2 and 1:3 (RPMS: EFB) based on volume/volume. The mixtures were filled in a polystyrene box up to 90% volume and water was sprinkled onto the compost (50% moisture content) to accelerate decomposition. During composting, the compost was turned every three days to ensure that the material on the outside of the pile was turned from the center outwards to dissipate heat. The RPMS and EFB compost mixtures were evaluated for physical, chemical, phytotoxicity and short term plant growth effects. These composts mixtures had no toxicity effects on plants, had 100% seed germination, high in nutrient contents, low in C/N ratio and had fine particle size of <18 mm. The concentrations of heavy metals were also within the recommended level of the Council of European Communities (CEC) for compost. Compost produced from a ratio of 1:1 volume is suitable for land application as compared to 1:2 and 1:3 (RPMS: EFB). However, further study should be carried out to evaluate the effect of raw and RPMS compost on soil fertility, plant productivity and quality.

Key words: Compost quality, nutrients, heavy metals, phytotoxicity, compost

INTRODUCTION

Recycled Paper Mill Sludge (RPMS) is the final processed wastes from pulp and paper industries generated from different stages of paper making. At present, Malaysia generates about 1 million metric tonnes of RPMS annually from 19

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mills. All paper industries produce sludge and these quantities are accumulating every year which leads to environmental problems in the country. Current practice is landfill disposal, which might not be viable in the long run as land is getting scarce and land cost is becoming more expensive. Some of the wastes from the paper manufacturing mill are categorized under hazardous toxic waste by the Department of Environment, Malaysia, and therefore, these wastes are classified as scheduled waste and unutilized in Malaysia. However, studies need to be carried out to investigate the potential use of RPMS as a value added product, an approach that may partly solve the disposal problem.

According to Das *et al.* (2002), composting paper sludge could be a promising technology in reducing waste problems by converting complex materials into useful soil amendments. According to Pe'rez-Piquarez *et al*. (2006), compost amendments modify the microbial community composition and decrease plant pathogens activity by enhancing competition and antagonism among microbes and reducing mass and volume, which makes compost suitable for agricultural applications. Several studies on the feasibility and the advantage of composting pulp and paper mill sludge have been carried out mainly in the temperate countries, especially on the composting processes, physical, chemical and microbial characteristics of the compost and the suitability of compost for plant growth (Atikinson *et al*., 1997; Graydon *et al.* 1999 and Marche *et al.*, 2003). According to Marche *et al.* (2003), composting paper mill sludge with hardwood sawdust could be successfully achieved with parameters such as aeration, moisture and close monitoring of C/N ratio. Another waste that needs to be disposed off is the empty fruit bunch (EFB). Total oil palm planted area in Malaysia increased from 3.90 million hectares in year 2005 to 4.69 million hectares in 2009 (MPOB 2010). For every ton of fresh fruit bunches, 0.2 ton of EFB is generated (Chan *et al.* 1981). Therefore, composting RPMS with EFB (as a bulking agent) could be an alternate method to reduce waste disposal in the country.

This study was conducted to determine the physico-chemical characteristics of composted RPMS and EFB mixtures, their phytotoxicity, and the effect of the composts on plant growth performance.

MATERIALS AND METHODS

Recycled Paper Mill Sludge and Shredded Empty Fruit Bunches

Raw recycled paper mill sludge from the biological treatment pond was obtained from United Paper Board, in Ijok, Selangor. The EFBs were obtained from Jugra Palm Mill Sdn. Bhd. at Banting, Selangor, and shredded into small pieces.

Experimental Design and Treatment

The composting experiment was carried out on a small scale by using a polystyrene box measuring 0.6 m (length), 0.5 (width) and 0.4 (height). Composting was conducted in the glasshouse unit of the Faculty of Agriculture, Universiti Putra Malaysia. The experiment was arranged in a completely randomized design

(CRD) with four replicates. The RPMS were mixed with EFB fibre in 3 ratios, that is 1:1, 1:2 and 1:3 (RPMS: EFB) based on volume/volume. For example 1:1 ratio equals to 3 kg RPMS mixed with 0.3 kg EFB based on fresh weight. The mixtures were filled in the polystyrene box up to 90% volume. Water was sprinkled onto the compost to keep the mixture moist at about 50% moisture content to accelerate decomposition. During composting, the compost was turned every three days to ensure that the material on the outside of the pile was turned from the center outwards to dissipate the heat. The temperature in the core of the material was recorded.

Compost Analysis

Compost was sampled from each box during composting for the analysis of NH_4^+-N, NO_3^- -N, Total N and Total C. The composts were analyzed for their maturity at 90 days of composting after the temperature stabilized. Percentage of volume reduction was calculated by taking the difference between the volume of the composting material at the beginning and volume of the compost after the composting for 90 days. The composting materials were monitored for changes in physical (color and odour) and chemical properties. The pH of the compost was determined from the supernatant of the mixed sample and distilled water ratio of 1:2.5 using a Beckman Digital pH meter. EC was measured from a solution collected from the saturated paste using the EC meter. Total carbon was measured by the combustion technique (Merry and Spounce, 1988) using a CR-412 carbon analyzer (LECO Corporation, St. Joseph, USA). Organic matter (OM) content was calculated from loss on ignition (correction factor of 1.78). Total nitrogen was determined using the modified Kjeldahl method (Bremner and Mulvaney, 1982). Mineral N (NH_4^+-N and NO_3^--N) was extracted with 40 mL of 2 M KCl according to Bremner (1965). Soil exchangeable bases (K^+, Ca^{2+}, and Mg^{2+}) and CEC was determined by the NH_4OAc (pH 7.0) method (Thomas, 1982). The leached bases were then determined by the PE 5100 atomic absorption spectrophotometer. Adsorbed NH_4^+ was displaced with potassium sulfate solution and determined using the auto-analyzer (Quickchem, FIA 8000, Lachat Instruments, and USA). Total PAHs were determined to the method described by Zakaria *et al.,* 2002. Total heavy metals were extracted using the aqua-regia solution (1:3 HCl: HNO_3) (Zarcinas *et al.* 1987) and the extracted metals were determined using the PE5100 atomic absorption spectrophotometer (Perkin Elmer, Wellesley, MA).

Test for phytotoxicity of composts

Germination Test: Ten gram fresh weight of compost was extracted with 100 mL distilled water and shaken for 2 hours, then filtered through a Whatman No. 1 filter paper. A 3 mL aliquot of extract was pipetted onto a Whatman No. 1 filter paper in a petri dish with 15 seeds of green bean and sweet corn. Plates were incubated at 27^0C for 24 hours. The control plates were also prepared using distilled water. The number of germinated seeds and average root length per dish were expressed in percentage based on control. Phytotoxicity results were expressed as germination

index obtained from the percent germination and percent root length divided by 100 (Zucconi *et al.* 1985).

Potting Media. The effect of the compost on plant growth was tested. It was tested in a small container (10 cm height x 7 cm width) with 6 treatments and 4 replicates. The treatments were: a) control (mineral soil), b) raw RPMS alone, c) commercial compost (empty fruit bunch composted with palm oil mill effluent), d) 1:1 e) 1:2 and f) 1:3 ratio of RPMS: EFB, respectively. Seeds of chillies, corn and tomato were used as test plants to determine plant growth performance at 14 days after sowing.

Statistical Analysis

All experimental data were analyzed statistically using analysis of variance (ANOVA). Tukey test was used for comparison of treatment means at $p<0.05$ (SAS 2006).

RESULTS AND DISCUSSION

Characteristics of Raw Recycled Paper Mill Sludge and Shredded Empty Fruit Bunches.

The physical and chemical properties of RPMS and EFB fibers are shown in Table 1. The raw RPMS were wet, sticky and formed cakes and emitted an unpleasant odour with moisture content of about 70%. The EFB were fibrous and this condition allows air to pass freely through the compost pile (Suhaimi and Ong, 2001). Therefore, EFB was considered a quality material for composting. According to Kala *et al*. (2009), compared to the frond and trunk, EFB fibre mixtures with sewage sludge resulted in a more rapid rise in temperature.

The pH of RPMS was alkaline (7.18) and this indicates its usefulness as a liming agent for amelioration of acid soils. The concentration of N in RPMS was 4.05 %, most probably due to addition of N in treatment pond. Gauthier *et al*. (2000) reported that majority of pulp and paper mill bio-treat their effluent by adding a large amount of ammonia or urea to the aeration tanks to allow for microbial growth. The result shows that the total Polycyclic Aromatic Hydrocarbons (PAHs) concentration in RPMS is considered low at 218 ng g^{-1}. Meanwhile, the concentration of dioxin in RPMS was 4.87 pg g^{-1} which is below the recomended value by USEPA. Therefore, RPMS does not pose any toxicity problem to the environment.

In general, the concentration of heavy metals in RPMS and EFB did not exceed the Maximum Permitted Concentration (MPC) for land application (Table 1). This is the metal threshold limit recommended by EU Commission working document for metal contamination for land application of sludge (Commission of European Communities 1986). Sludge should not be used if one or more values exceed the limit. Therefore, it is important to closely monitor the effect of RPMS utilization as materials for composting as they may pose metal toxicity hazard.

TABLE 1
Characteristics of recycled paper mill sludge (RPMS) and shredded empty fruit bunches (n=6)

Parameter	EFB	RPMS	*MPC
Odour	nd	strong unpleasant odour	
Colour	10YR 5/4	10YR 3/1	
pH	nd	7.18	
EC, mS^{-1}	nd	3.08	
Organic matter, %	55.37	38.67	
Nitrogen, %	1.05	4.05	
Carbon, %	44.19	33.67	
C/N ratio	42.08	8.33	
CEC, $cmol_c\ kg^{-1}$	nd	28.07	
P, %	0.05	0.78	
K, %	1.91	0.42	
Ca, %	1.54	0.53	
Mg, %	0.07	0.45	
Al, %	0.45	2.76	
Fe, %	0.04	0.17	
As, $mg\ kg^{-1}$	108	186	
Cd, $mg\ kg^{-1}$	1.84	4.09	20-40
Cr, $mg\ kg^{-1}$	29.45	37.01	
Cu, $mg\ kg^{-1}$	19.20	88	1000-1750
Mn, $mg\ kg^{-1}$	50.77	325	
Pb, $mg\ kg^{-1}$	11.95	177	750-1200
Zn, $mg\ kg^{-1}$	29.88	251	2500-4000
Ni, $mg\ kg^{-1}$	18.61	25.21	
PAHs, $ng\ g^{-1}$	nd	218	
Dioxin, $pg\ g^{1}$	nd	4.87	[a]50

nd – not detected
* maximum permitted concentration (Commission of European Communities, 1986)
[a] USEPA

Compost Characteristics during Composting

The temperatures of composts are shown in Figure 1. The ratio 1:1 of RPMS: EFB reached 40.21 ºC, 1:2 ratio of RPMS: EFB reached 43.15 ºC, while the ratio 1:3 of RPMS: EFB reached 44.80 ºC after 3 days of composting. In this study, it was observed that the compost did not reach thermophilic stage (> 45 ºC), probably due to heat dissipation because of its small volume (Kala *et al*. 2009). This was only a preliminary study to determine the best compost mixture therefore smaller volume was used. The factors controlling temperature rise in a compost pile are type of microorganisms present, materials used for composting, amount and height of the compost and moisture content. Generally, the temperatures of the composts were in the range of 29.0 to 44.80 ºC. During the maturing stage, temperature decreased and stabilized from 29.00 to 30.07 ºC after 60 days of composting. The composting process was completed when the temperature at the center of the compost heap had cooled down to the ambient air temperature from 60 to 90 days after composting. At this stage, the bio-oxidation phase of composting was considered completed (Hachicha *et al.* 2008).

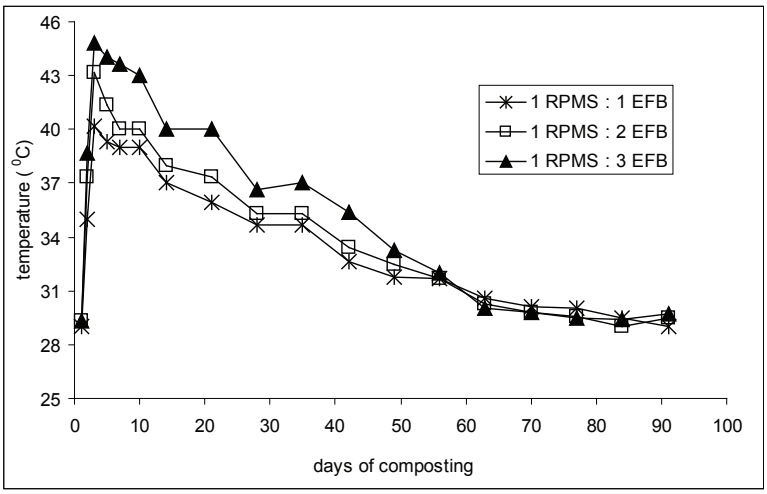


Fig. 1: Changes in temperature of the composting of RPMS and EFB at different ratios during 90 days of composting

The C/N ratio of RPMS and EFB mixture were within the range of 37 to 41. After 90 days of composting, the C/N ratio decreased 47% (less than 20) (*Fig. 2)*. As the composting process progressed, the C:N ratio decreased because a large part of the C was continuously released as CO_2 while the majority of the N was recycled through the cellular material of the microorganisms (USDA, 2000). The NH_4^+-N and NO_3^--N are two important components of mineral N presents in matured composts. In the early stage of composting, mineralization of organic N and other nitrogenous compounds such as protein mineralizes N to ammonium occurs. Upon oxidation of NH_4^+-N by oxidizing bacteria, NO_3^- -N is accumulated.

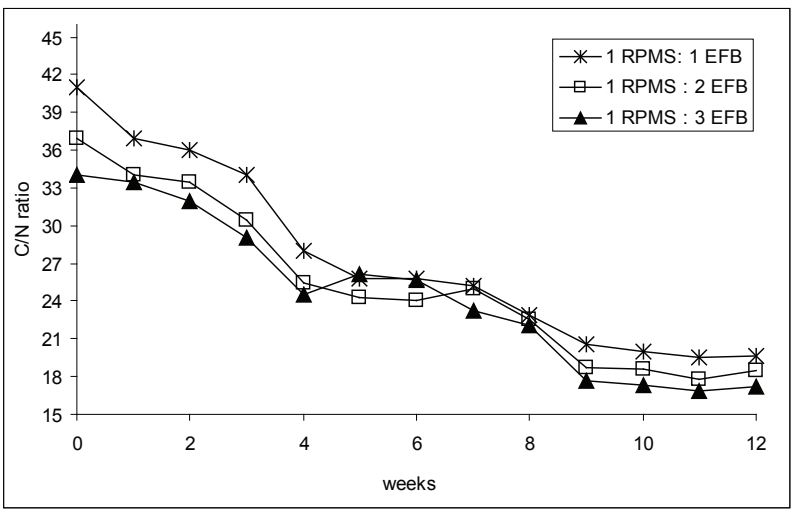


Fig. 2: Changes in C/N ratio of the composting of RPMS and EFB at different ratio during 90 days of composting

Thus, in matured compost, NO_3^- -N should be higher than NH_4^+-N. This study proves that the composts produce higher NO_3^- -N compared to NH_4^+-N (*Figs. 3 and 4*).

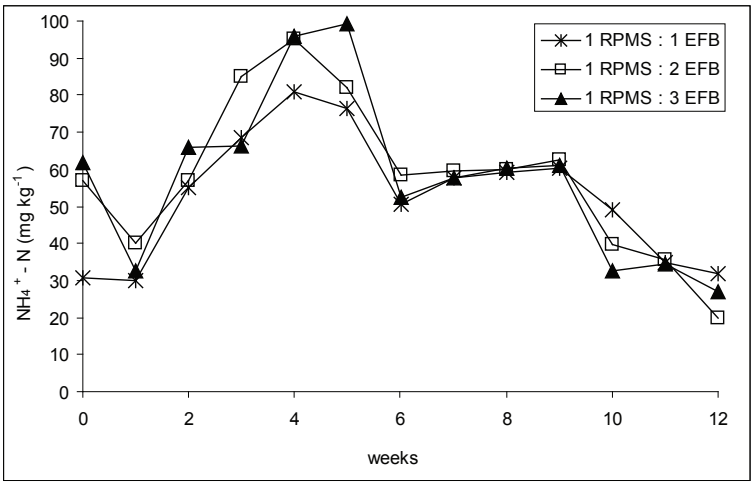


Fig. 3: Changes in NH_4^+ -N ratio of the composting of RPMS and EFB at different ratio during 90 days of composting

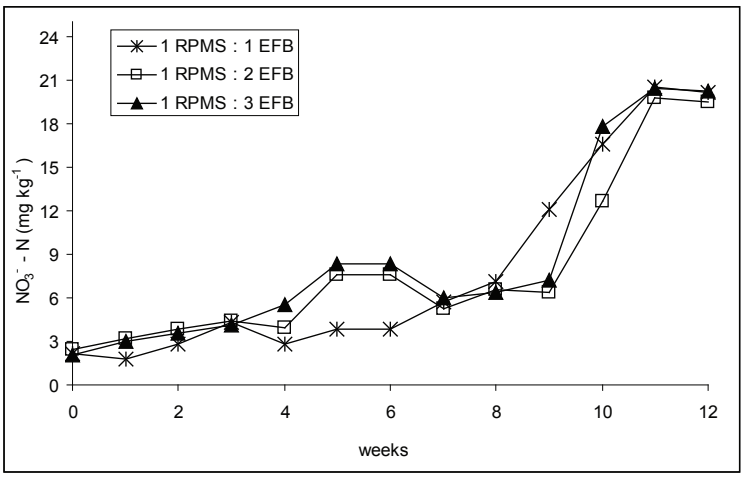


Fig. 4: Changes in NO_3^- -N ratio of the composting of RPMS and EFB at different ratio during 90 days of composting

Characteristics of RPMS Compost after 90 Days of Composting

Figure 5 shows the three composts mixtures (RPMS: EFB) after 90 days of composting. The stability of the compost occurs when it resembles humus, has an earthy smell and is dark brown to black in color. After 90 days of composting, composts with 1:1 of RPMS: EFB ratio had < 10 mm in particle size compared

to 1:2 and 1:3 of RPMS: EFB which had particle size of <16 and <18 mm, respectively. The percentage of volume reduction of three compost mixtures after 90 days varied widely, 60.96 % in 1:1, 70.45 % in 1:2 and 72.12 % in 1:3 ratio of RPMS: EFB. The lower ratio of EFB in RPMS and EFB compost mixture may be compacted with RPMS compared to the higher ratio of EFB.

All of the three RPMS: EFB compost mixtures could be graded as good quality based on their pH and organic matter which are in the range of the regulation values by Council of European Communities (CEC) for compost. The value C:N ratio obtain from this study ranged from 17.20 to 19.60 which is within the recommended value by the Council European Communities (CEC 1986) for compost (<22). Nitrogen concentration was higher in 1:1 followed by 1:2 and 1:3 RPMS: EFB

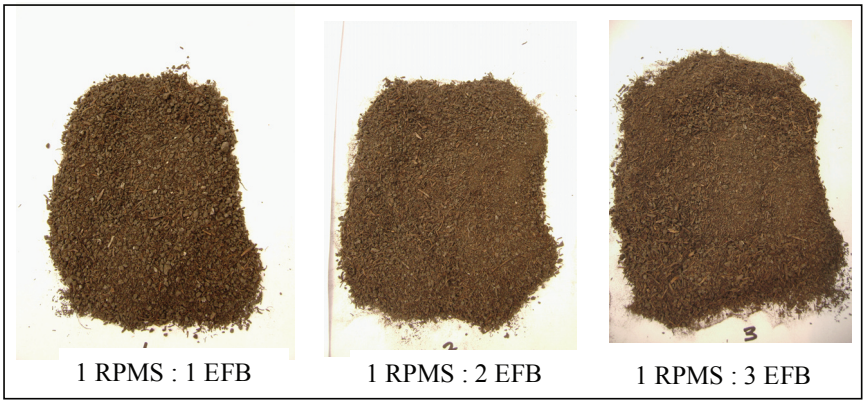


Fig. 5: The color of RPMS and EFB compost mixtures after 90 days of composting

compost mixtures (2.68, 2.38 and 2.03 %, respectively). However there were no significant differences between 1:1 and 1:2 ratio of RPMS: EFB compost mixture after 90 days of composting compared to the 1:3 ratio (Table 2). The percentage of K was highest in the 1:3 ratio compost mixture and this may have come from the EFB.

The heavy metals content in the RPMS: EFB compost mixtures after 90 days of composting are shown in Table 3. The heavy metals content of RPMS need to be monitored as they may pose a hazard of metal toxicity to crops. Due to the reduction in volume during composting, an increase in the concentration of heavy metals was observed in the final compost products. However, the concentrations of heavy metals were within the recommended level of the Council of European Communities (CEC) for compost in all three RPMS:EFB compost mixtures. Therefore these RPMS: EFB compost mixtures could be recommended for land application in Malaysia. Except for Cu and Ni, there were also no significance difference in the concentration of As, Cd, Cr, Mn, Pb, Zn and Fe in these compost mixtures. However studies need to be conducted to determine the long term effect of RPMS: EFB compost mixtures on soil.

Phytotoxicity Test

Phytotoxicity test on sweet corn and green beans were performed on the composts'

extracts and the results showed that the three RPMS: EFB compost mixtures had 100% germination (Table 4) suggesting they are non-toxic and suitable for seed germination. The results show that RPMS:EFB compost mixtures with ratio 1:1 and 1:2 had no significant differences on the germination, root length and germination index in sweet corn and green beans seeds compared to the 1:3 ratio.

TABLE 2
Physical and chemical characteristics of the RPMS and shredded EFB at different ratios after 90 days of composting

Parameter	Compost 1:1 (RPMS:EFB)	Compost 1:2 (RPMS:EFB)	Compost 1:3 (RPMS:EFB)	* Regulation value
Odour	Produced humus-like odour	Produced humus-like odour	Produced humus-like odour	
Colour	10YR 2/1	10 YR 2/2	10 YR 2/2	
Volume reduction, %	60.96 c	70.45 b	72.12 a	
Particle size (mm)	<10	<16	<18	<24
pH	7.18 a	7.41 a	7.52 a	5.5-8.0
EC, mS^{-1}	4.84 a	5.56 a	5.32 a	
Organic matter, %	61.62 b	67.67 a	69.19 a	>30
Nitrogen, %	2.68 a	2.38 ab	2.03 b	0.6[a]
Carbon, %	52.52 a	44.03 ab	34.90 b	
C/N ratio	19.60 a	18.50 ab	17.20 b	<22
CEC, $cmol_c\ kg^{-1}$	28.61 a	29.67 a	31.93 a	
P, %	0.71 a	0.73 a	0.63 a	
K, %	0.69 b	0.91 ab	1.37 a	
Ca, %	0.47 a	0.48 a	0.43 a	
Mg, %	0.29 a	0.29 a	0.30 a	
Al, %	2.84 a	0.84 b	1.45 b	

Same letters in the row indicate that the values are not significantly different at p>0.05, according to Tukey test.
* recommended by Council of European Communities (CEC) for compost, source: Zucconi and Bertoldi 1987)
[a] minimum mineral content (% dry wt.)

TABLE 3
Heavy metals concentrations of RPMS and shredded EFB at different ratios after 90 days of composting compared to the regulation value.

Heavy Metal	Compost 1:1 (RPMS:EFB)	Compost 1:2 (RPMS:EFB)	Compost 1:3 (RPMS:EFB)	* Regulation Value
As, $mg\ kg^{-1}$	150 a	100 a	108 a	
Cd, $mg\ kg^{-1}$	2.48 a	2.48 a	2.71 a	5
Cr, $mg\ kg^{-1}$	15.33 a	26.85 a	27.86 a	200
Cu, $mg\ kg^{-1}$	87.71 a	86.09 ab	79.99 b	150
Mn, $mg\ kg^{-1}$	342 a	449 a	378 a	
Pb, $mg\ kg^{-1}$	26.94 a	26.97 a	21.45 a	750
Zn, $mg\ kg^{-1}$	183 a	228 a	199 a	1000
Ni, $mg\ kg^{-1}$	20.29 b	24.71 a	21.47 ab	50
Fe, %	0.17 a	0.20 a	0.17 a	

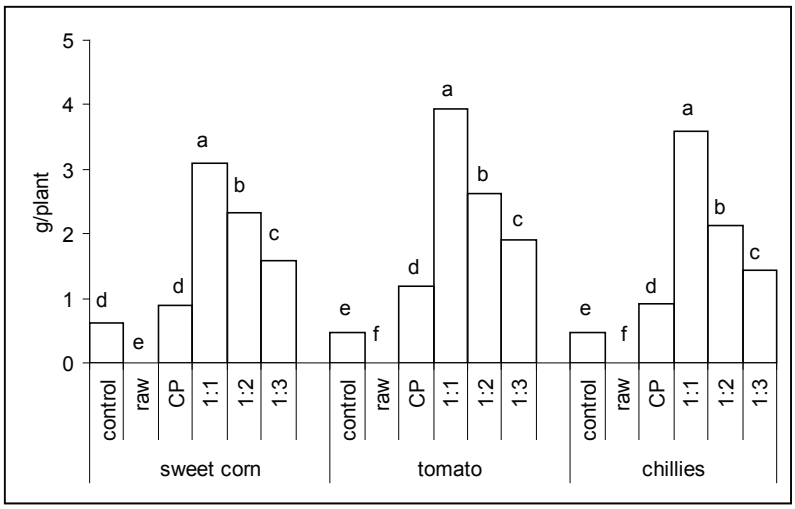
Same letters in the row indicate that the values are not significantly different at p>0.05, according to Tukey test.
* recommended by Council of European Communities (CEC) for compost, source: Zucconi and Bertoldi 1987)

TABLE 4
The effect of RPMS and EFB compost mixtures on the phytotoxicity germination test of sweet corn and green bean

10% compost extract	Percent germination	Percent root length	Germination Index	Percent germination	Percent root length	Germination Index
	Green Bean			Sweet corn		
Control (Distilled Water)	100	100a	2.00a	100	100a	2.00a
RPMS 1: EFB 1	100	95.38a	1.95a	100	98.53a	1.98a
RPMS 1: EFB 2	100	87.72ab	1.88ab	100	79.15ab	1.79ab
RPMS 1: EFB 3	100	63.51b	1.63b	100	69.46b	1.69b

Same letters in the column indicate that the values are not significantly different at p>0.05, according to Tukey test.

Figure 6 shows the effects of raw RPMS, RPMS and EFB compost mixtures compared to commercial compost as a potting media on the dry matter weight of sweet corn, tomato and chilies after 14 days of planting. Generally, the dry matter weight of sweet corn, tomato and chillies showed the same trend. The dry matter weight of these plants decreased with increasing content of EFB in the RPMS: EFB compost mixtures. This could be due to the lower N content and C/N ratio in these potting media. Potting media containing composts of 1:1 ratio RPMS: EFB exhibited the highest dry matter weight in sweet corn, tomato and chillies compared to the other treatments. However, the plants could not survive in raw RPMS alone as potting media, as shown in Figure 7.



Same letters above bars indicate that the values represented by the bars within crop are not significantly different at p>0.05, according to Tukey test.

Fig. 6: The effect of raw RPM, RPMS and EFB compost mixtures compared to commercial compost on the dry matter weight of sweet corn, tomato and chillies after 14 days planting. The treatments are: a) C, control (mineral soil), b) raw, raw RPMS alone, c) CP, commercial compost and d) 1:1; 1:2; 1:3 (RPMS:EFB) compost ratios.

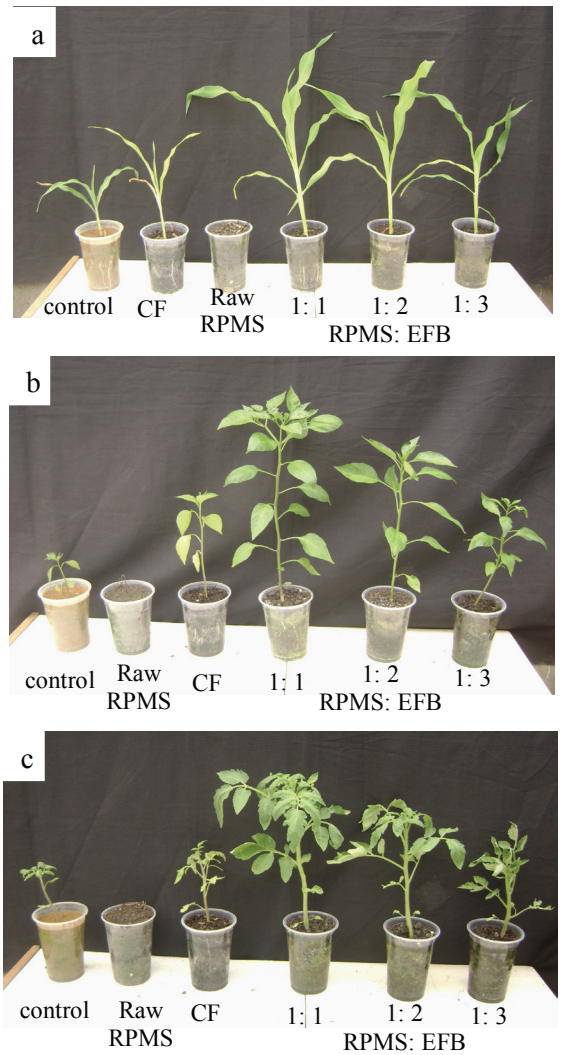


Fig.7: The effect of raw RPM, RPMS and EFB compost mixtures compared to commercial compost on the dry matter weight of a) sweet corn, b) tomato and c) chillies after 14 days planting. The treatments are a) control (mineral soil), b) raw RPMS, c) CF, commercial compost and d) 1:1; 1:2; 1:3 (RPMS:EFB) composts ratio.

CONCLUSION

This study suggests that RPMS and EFB has potential for re-utilization as compost for land application. These composts mixtures had no toxicity effects on plants, 100% seed germination, high in nutrient contents, low in C/N ratio and had fine particle size. The concentrations of heavy metal were also within the recommended level of the Council of European Communities (CEC) for compost. In conclusion, compost with 1:1 volume ratio could be used for land application

as compared to 1:2 and 1:3 (RPMS: EFB). Moreover usage of compost with 1:1 ratio will help the paper mill industry to recycle its waste as more RPMS will be used compared to other compost with other ratios which utilize more EFB. Studies on utilization of sludge from paper industry are still at an infancy stage in Malaysia. Long term studies should be carried out to evaluate the effect of raw and RPMS compost on soil fertility, plant productivity and quality.

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